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ANALYZING THE LEAN PRINCIPLES IN INTEGRATED PLANNING AND SCHEDULING METHODS

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ABSTRACT

The shortcomings and limitations of conventional planning and scheduling methods led to a great deal of emphasis on combining them and developing integrated scheduling methods. Also, lean principles and tools are included in the integrated scheduling methods' structure to develop more effective scheduling strategies. This paper implements a multi-step methodology to identify and analyze the lean principles utilized in integrated scheduling methods. The findings show that integrated scheduling methods, Building Information Modelling (BIM)-Last Planner System (LPS)-Kanban, BIM-LPS, Location-based Management System (LBMS)-LPS-CPM, and BIM-LBMS have included a variety of lean principles into their frameworks. Moreover, improving the reliability of the planning, increasing transparency, identifying and eliminating waste, detecting and solving spatiotemporal conflict, enabling the coordination of the look-ahead plans, and continuous flow of work have received the most attention in the integrated scheduling methods. This paper contributes significantly to the body of knowledge by raising project stakeholders' awareness of the lean principles utilized in integrated scheduling methods in construction projects.

KEYWORDS

Lean principles, Integrated Scheduling Methods, SNA, Quantitative Analysis

INTRODUCTION

The construction industry remains still among the lowest productivity rates across all sectors (Turner et al. 2020). Ineffective planning and scheduling (Al Hattab and Hamzeh 2016; Salama et al. 2021), a lack of effective communication and collaboration between stakeholders (Hamzeh et al. 2019; Khanzadi et al. 2020), unrealistic scheduling and inefficient resource management (Hamza et al. 2022) are some reasons for this issue. Thus, it consistently seeks innovative and productive methods for optimizing projects, reducing waste, and increasing efficiency. To overcome the challenges related to ineffective planning and scheduling, using lean principles and tools combined with conventional scheduling methods and developing

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integrated scheduling methods is an approach that has received considerable attention in recent years. (Abbasi et al. 2020; Aslam et al. 2020; Boton et al. 2021; Heigermoser et al. 2019). In line with this, several studies integrated the Last Planner System (LPS) with Building Information Modelling (BIM) to improve productivity and efficiency, promote continuous improvement, increase understanding of project stakeholders, and improve the reliability of the planning (Barkokebas et al. 2021; Heigermoser et al. 2019; Sacks et al. 2010; Schimanski et al. 2020; Schimanski et al. 2021). In addition, Abdelmegid et al. (2021) established a framework for adopting simulation modelling in construction by integrating the LPS with simulation modelling approaches. Novinsky et al. (2018) combined the LPS with Earned Value Management (EVM) to improve transparency and control project progress concerning time and cost. Moreover, Ammar (2013) integrated the Critical Path Method (CPM) and Line of Balance (LOB) to consider both logic dependency and resource continuity constraints for repetitive projects. Seppänen et al. (2010) developed an approach that combined the benefits of LPS and Location-based Management System (LBMS) to achieve the lean goals of decreasing waste, increasing productivity, and decreasing variability. Although integrated scheduling methods have primarily addressed the shortcomings of traditional and common scheduling methods, like CPM, and provide the project manager with a wider range of capabilities, a lack of understanding of their underlying concept and incredibly lean principles used make it challenging for the project manager and scheduler to choose the practical and required approach for planning and scheduling.

This study seeks to identify and assess a list of lean principles utilized in integrated scheduling methods in the construction industry. Furthermore, it provides project managers, planners, and schedulers with new insights into the underlying lean principles used in integrated scheduling methods to improve planning and scheduling effectiveness. The following sections provide an overview of the research methodology, analyses and results, a discussion of research findings, and, eventually, recommendations for further research in this field of study.

RESEARCH METHODOLOGY

As shown in Figure 1, a multi-step methodology is employed to achieve this study's objectives.

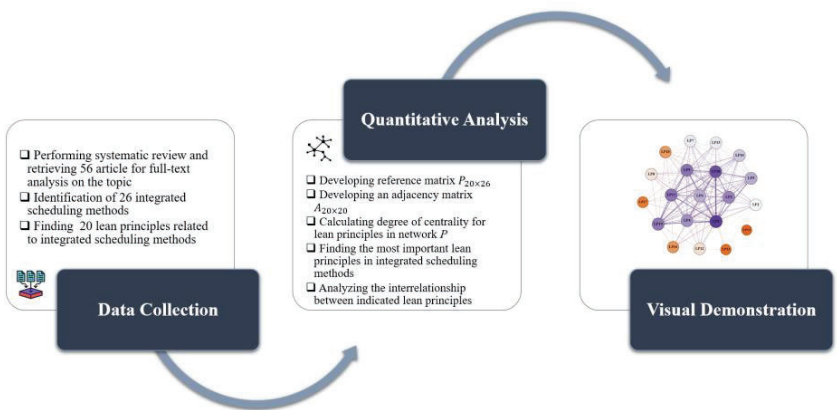

Figure 1: A brief overview of the adopted multi-step research methodology

This study's methodology consists of the following steps: (1) a Systematic Literature Review (SLR) on integrated planning and scheduling methods in the construction industry; (2) identification of lean principles applied in the integrated scheduling methods; and (3) using Social Network Analysis (SNA) to quantify most important lean principles in the integrated scheduling methods. The following sections outline the research methodology's components in more detail.

SYSTEMATIC LITERATURE REVIEW

The applied SLR consists of three components: (1) paper identification, (2) screening; and (3) content analysis conducted by a quantitative literature analysis using SNA. Conference proceedings and peer-reviewed construction journal papers were considered to collect data. As shown in Table 1, the search string was created by combining scheduling methods with "AND" and "OR" in the Web of Science (WoS) database. Title, abstract, and keywords were searched till December 2022, resulting in 1283 publications.

Table 1: Search keywords

Search Query
TS=(("CPM" OR "Critical Path Method" OR "PERT" OR "CCPM" OR "Critical Chain Management system" OR "Critical chain method" OR "LOB" OR "Line of Balance" OR "LPS" OR "Last Planner System" OR "Takt Planning" OR "Takt time planning" OR "LBMS" OR "Location Based Management System" OR "BIM" OR "Building Information Modeling" OR "4D" OR "4DBIM" OR "Linear Scheduling Method" OR "LSM" OR "Simulation" OR " Monte-Carlo") AND ("Project Planning" OR "Project Scheduling" OR "Construction Planning" OR "Construction Scheduling"))

The screening phase is conducted based on several inclusion criteria, such as choosing articles written in English and including at least one combination of scheduling methods (i.e. LPS-LSM). After the screening phase, content analysis was performed on 56 acquired papers to identify the lean principles used in the integrated scheduling methods. To do this, the finalized papers based on 26 identified integrated scheduling methods were analyzed and coded using Nvivo Qualitative Data Analysis software to extract the lean principles associated with each integrated scheduling methods. After that, first, 26 integrated scheduling methods were considered essential and beneficial for the aim of this study. Second, 38 lean principles were extracted from 56 approved papers. The authors tried to aggregate the principles with same concept such as reducing the cycle time with identifying and eliminating of wastes, resulting 20 lean principles for further analysis. It should be mentioned that the codifying and extracting lean principles were applied by this research's first author and evaluated and approved by the other authors of the article.

QUANTITATIVE ANALYSIS OF LEAN PRINCIPLES

The SNA facilitates researchers' efforts to discover systematic literature-related outcomes by connecting concepts, themes, and ideas missed by manual review evaluations due to its quantitative strength and capacity to evaluate interrelationships among numerous factors (Elsayegh and El-adaway 2021). So, same as other studies for quantitative analysis of the collected data from the literature (Assaad and El-Adaway 2020; Elsayegh and El-adaway 2021; Hosseini et al. 2018; Saedi et al. 2022), the authors chose SNA as the best approach for assessing and identifying the most highlighted lean principles in the integrated scheduling methods. A reference matrix P must first be developed to perform SNA on the extracted lean principles. The rows of this matrix reflect recognized lean principles, while the columns indicate integrated scheduling methods. The second step is constructing an adjacency matrix based on the reference matrix P. A weighted adjacency matrix is computed by multiplying the reference matrix P by its transpose and then removing and replacing the values in the diagonal cells of the resulting matrix with zeros. Equation 1 is used to construct this matrix. This matrix represents a network where the rows and columns represent lean principles, and the cell values indicate the co-occurrence frequency of each lean principle.

$$A_{l\times l} = \begin{cases} P_{l\times m} \times P_{l\times m}^{T} & for\ i \neq j \\ 0 & for\ i = j \end{cases} \tag{1}$$

Where $A_{l\times l}$ = weighted adjacency matrix; $P_{l\times m}$= reference matrix; $P_{l\times m}^{T}$= transpose of the reference matrix where i and j are the row and column indexes of the reference matrix, respectively.; l = the number of identified lean principles (i.e., 20); and m = the number of integrated scheduling methods (i.e., 26).

In addition, degree centrality (DC) was utilized to evaluate the significance of a given lean principle based on its frequency and association with other lean principles. The DC for each lean principle is calculated based on Equation 2.

$$DC_i = \sum_{j;j\neq i} P_{i,j} \tag{2}$$

Where DC_i is the degree of centrality for lean principle i and $P_{i,j}$ is the value of the cell in row i and column j of the adjacency matrix. Since the DC calculation depends on the size of the relevant network, it was decided to normalize it. According to Equation 3, the normalized DC of a lean principle i in a network equals the DC of the evaluated lean principle divided by the highest DC of the network.

$$\overline{DC_i} = \frac{DC_i}{max\,\{DC_k\}} \tag{3}$$

Therefore, all lean principles reflect a DC_i normalized between 0 and 1.

RESULTS AND ANALYSIS

The systematic search and screening efforts provided 56 approved journal and conference papers from 1994 to 2021, as indicated in the methodology. By reviewing the contents of the papers, the authors found 20 lean principles in 26 integrated scheduling methods, detailed in Table 2 and Table 3. As shown in Table 3, the 26 integrated scheduling methods were established by merging 14 conventional scheduling methods with lean tools, such as the last planner system, Kanban, six sigma, Just-in-Time (JIT), and takt time. Furthermore, Figure 2 shows the mapping of studied integrated scheduling methods and the identified lean principles. Purple cells indicate that the integrated scheduling methods have attempted to meet lean principles. BIM-LPS-Kanban, BIM-LPS, LBMS-LPS-CPM, and BIM-LBMS have incorporated various lean principles into their frameworks.

Table 2: Identified lean principles

ID	Lean Principles
LP1	Improving the reliability of the planning
LP2	Increasing productivity
LP3	Continuous flow of work
LP4	Decreasing workflow variability
LP5	More efficient constraints analysis
LP6	Visualizing of schedules to understand and communicate content to a variety of stakeholders
LP7	Avoiding omissions and sequencing mistakes
LP8	Schedule constructability analysis
LP9	Identifying and eliminating of waste
LP10	Decreasing meeting durations
LP11	Detecting and solving spatiotemporal conflicts
LP12	Maintaining continuity of resources
LP13	Scheduling of modular and offsite construction
LP14	Eliminating the root causes of variability
LP15	Reducing of production cycle time
LP16	Improving the usability of the 4D BIM for workflow analysis
LP17	Increasing safety on construction sites
LP18	Increasing transparency
LP19	Enabling the coordination of the lookahead plans
LP20	Implementing of pull flow control

Table 3: Highlighted integrated scheduling methods

ID	Integrated Scheduling Methods	Abbreviations
1	4D BIM-Last Planner System	4D-LPS
2	4D BIM-Linear Scheduling Method	4D-LSM
3	BIM-Just In Time	BIM-JIT
4	BIM-Location-Based Management System	BIM-LBMS
5	BIM-Last Planner System	BIM-LPS
6	BIM-Last Planner System-Kanban	BIM-LPS-Kanban
7	BIM-Simulation Modeling	BIM-SM
8	BIM-Takt Time Planning	BIM-TTP
9	BIM-Takt Time Planning- Simulation Modeling	BIM-TTP-SM
10	Critical Chain Project Management- Last Planner System	CCPM-LPS
11	Critical Chain Project Management- Last Planner System- Linear Scheduling Method	CCPM-LPS-LSM
12	Critical Path Method- Location-Based Management System	CPM-LBMS
13	Critical Path Method- Last Planner System	CPM-LPS
14	Earn Value Management- Last Planner System	EVM-LPS
15	Location-Based Management System- Critical Chain Project Management	LBMS-CCPM
16	Location-Based Management System- Last Planner System- Critical Path Method	LBMS-LPS-CPM
17	Line of Balance - Critical Path Method	LOB-CPM
18	Line of Balance- Monte Carlo Simulation	LOB-Monte Carlo
19	Last Planner System-BIM-Simulation Modeling	LPS-BIM-SM
20	Last Planner System- Location-Based Management System	LPS-LBMS
21	Last Planner System- Line of Balance- Simulation Modeling	LPS-LOB-SM
22	Last Planner System- Six Sigma	LPS-SS
23	Linear Scheduling Method- Critical Chain Project Management	LSM-CCPM
24	Last Planner System- Simulation Modeling	LPS-SM
25	Critical Path Method- Simulation Modeling	CPM-SM
26	Linear Scheduling Method- Critical Chain Project Management- BIM	LSM-CCPM-BIM

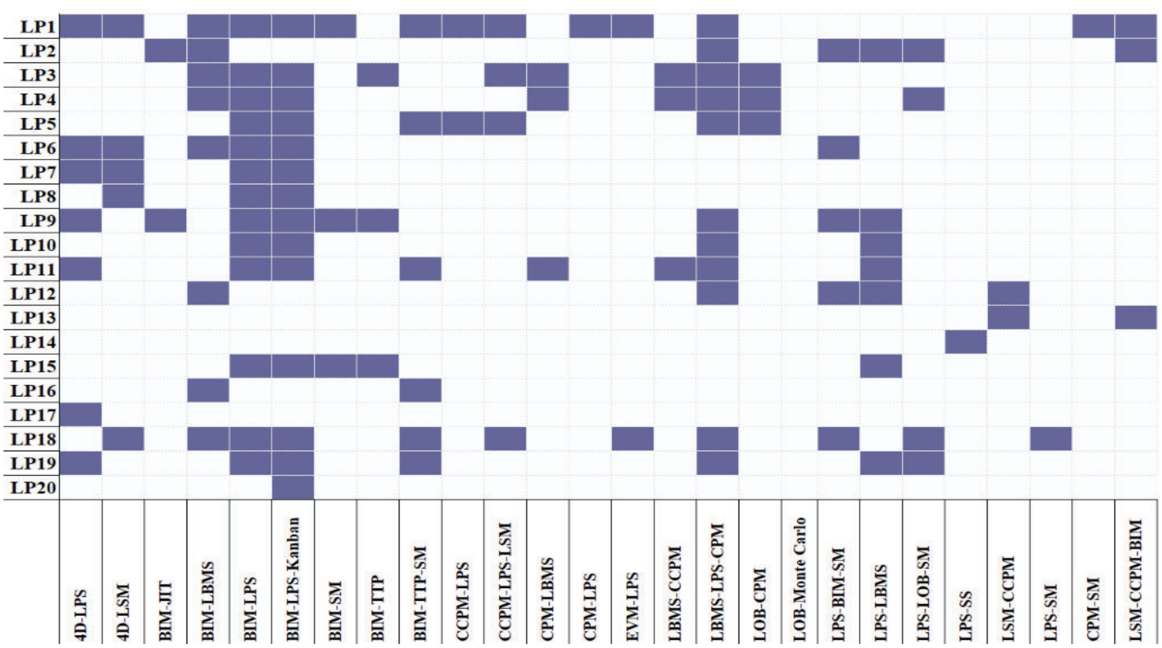

Figure 2: Mapping of studied integrated scheduling methods and the identified lean principles

QUANTITATIVE ANALYSIS OF LEAN PRINCIPLES

After conducting an in-depth analysis of the papers and identifying the lean principles, a reference matrix P was created based on those lean principles and integrated scheduling methods. The reference matrix P has a size of 20 by 26 and comprises 20 lean principles and 26 integrated scheduling methods. The following subsections describe the results.

Lean Principles Network

Using Equation 1, the authors created the adjacency matrix based on the reference matrix acquired from the literature analysis. The adjacency matrix's cell values indicate the weight of the edge connecting one node to another. The cells are color-coded based on the intensity of the edges between the pair of lean principles, illustrated in Figure 3. As can be seen, white-colored cells for a pair of lean principles imply that they have not co-occurred in any of the evaluated integrated scheduling methods. Consider LP2 (increasing productivity) and LP8 (schedule constructability analysis) for the latter. On the other hand, certain pairs of lean principles have dark orange cells, suggesting significant weights and, therefore, an abundance of co-occurrence in the integrated scheduling methods under consideration. This is represented in the edge weights between LP1 (improving the reliability of the planning) and LP18 (increasing transparency).

Moreover, as illustrated in Figure 4, the adjacency matrix is employed to visualize the lean principles network. The network diagram consists of 20 lean principles (nodes) linked by 266 directed edges or connections. The figure demonstrates that the network has several links between lean principles. In other words, the network of lean principles is dense, indicating numerous interconnections resulting from graph density equal to 0.778.

The degree of centrality (DC) is calculated and normalized to assess the interconnectivity among the lean principles in integrated scheduling methods. Table 4 displays the normalized DC results. In Figure 4, the dark purple colors correspond to lean principles with higher DC values, and the orange colors represent lean principles with lower DC values.

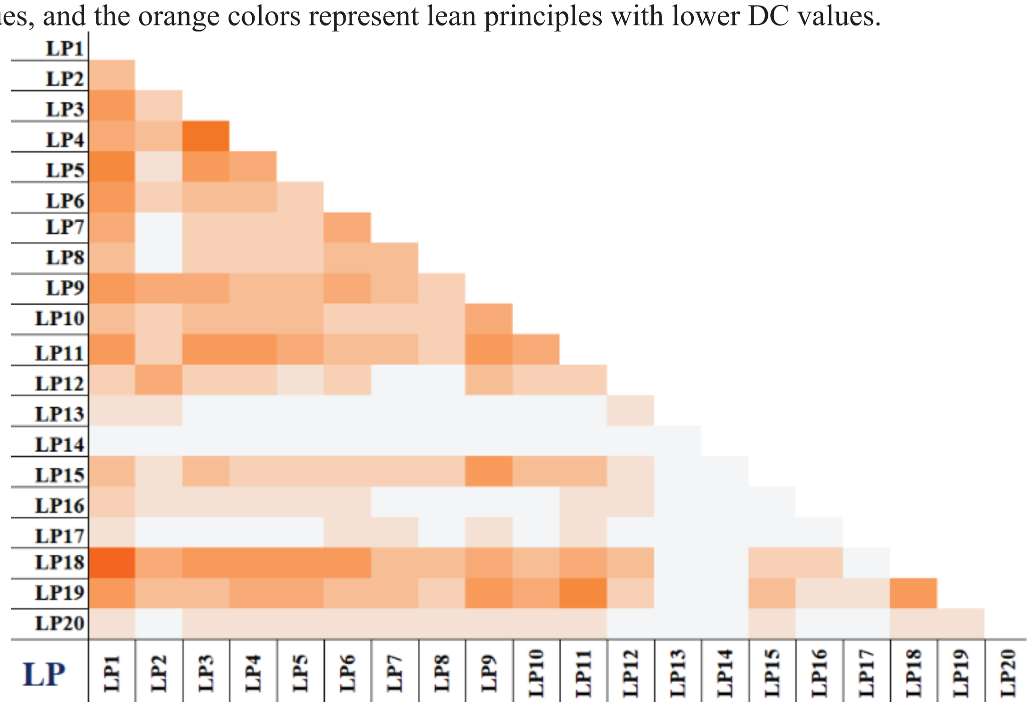

Figure 3: Color-coded adjacency matrix of lean principles

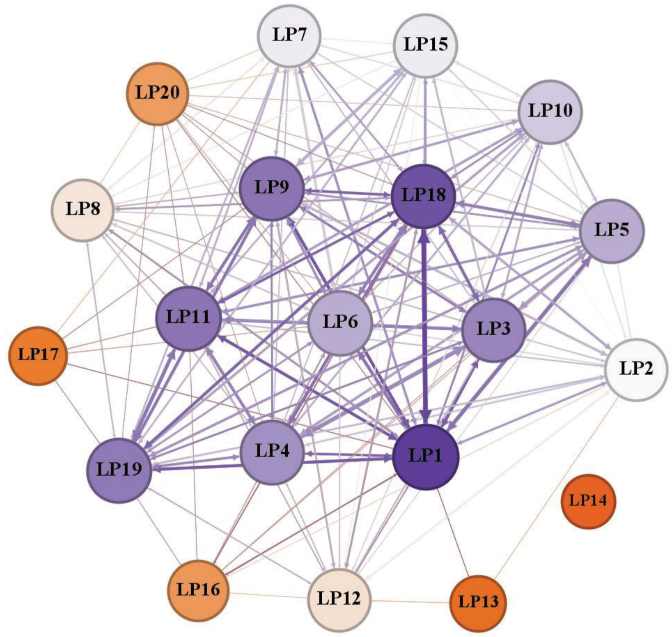

Figure 4: Lean principles network

Table 4: Normalized DC for lean principles

Code	Lean Construction Principles	Network P Normalized DC
LP1	Improving the reliability of the planning	1.00
LP18	Increasing transparency	0.94
LP9	Identification and elimination of waste	0.85
LP11	Detecting and solving spatiotemporal conflicts	0.85
LP19	Enabling the coordination of the look-ahead plans	0.83
LP3	Continuous flow of work	0.80
LP4	Decreasing workflow variability	0.77
LP5	More efficient constraints analysis	0.70
LP6	Visualization of schedules to understand and communicate content to a variety of stakeholders	0.70
LP10	Decreasing meeting durations	0.62
LP7	Avoiding omissions and sequencing mistakes	0.53
LP15	Reduction of production cycle time	0.53
LP2	Increasing productivity	0.50
LP8	Schedule constructability analysis	0.44
LP12	Maintaining continuity of resources	0.42
LP20	Implementation of pull flow control	0.20
LP16	Improving the usability of the 4D BIM for workflow analysis	0.18
LP17	Increasing safety on construction sites	0.09
LP13	Scheduling of modular and off-site construction	0.05
LP14	Eliminating the root causes of variability	0.00

Two perspectives on lean principles can be discussed: (1) the lean principles that have been employed most often in integrated scheduling methods, and (2) the lean principles that have been used the least frequently.

In regards to the first viewpoint, as shown in Figure 4 and Table 4, LP1 (improving the reliability of the planning), LP18 (increasing transparency), LP9 (identification and elimination of waste), LP11 (detecting and solving spatiotemporal conflicts), LP19 (enabling the coordination of the look-ahead plans), LP3 (continuous flow of work) have received the most attention in the integrated scheduling methods.

Following the second perspective, Figure 4 indicates that LP13 (scheduling of modular and off-site construction), LP17 (increasing safety on construction site), LP16 (improving the usability of the 4D BIM for workflow analysis), and LP20 (implementing of pull flow control) have been given the least importance by the integrated scheduling methods. Moreover, as seen in the network, there is no link for LP14 (eliminating the root causes of variability), indicating a lack of consideration for this principle in the integrated scheduling methods.

RESEARCH DISCUSSIONS

This section discusses the important results of this research in the context of identified lean principles in the integrated scheduling methods. This can be accomplished by highlighting areas that have gained considerable attention and those that have received little attention to determine future directions.

Understanding these integrated methods and the underlying concepts can enable project managers to optimize resources and processes more effectively. In support of this claim, several studies have discussed that a lack of knowledge and understanding of project scheduling methods, tools, and underlying concepts may lead to failures in project delivery (AlNasseri and Aulin 2015; Shash and Ahcom 2006). In this respect, this research investigated identifying and analysing the lean principles employed in integrated scheduling methods to assist project stakeholders in understanding the effectiveness of integrated scheduling methods. The findings indicated that the Last Planner System (LPS), Kanban, six sigma, Just-in-Time (JIT), and takt time were the most utilized lean tools in the integrated scheduling methods. Although many integrated scheduling methods, such as BIM-LPS, BIM-LPS-Kanban, LBMS-LPS, LPS-CPM, LPS-LSM, etc., have benefited from LPS advantages such as planning reliability, constraint management, continuous workflow, and continuous improvement, few integrated scheduling methods have focused on one of its shortcomings, which is the non-performance of root cause analysis and corrective actions (Aslam et al. 2020). In addition, the focus of some integrated scheduling methods, such as LPS-4D, LPS-BIM, and LPS-BIM-Kanban, on addressing one of LPS drawbacks, which is inadequate visualization capabilities (Aslam et al. 2020), demonstrates that there is a great deal of potential for the future of the industry, as well as research to focus on visual-based collaborative scheduling methods including Virtual Reality (VR)-LPS and metaverse-base LPS.

The results of the lean principles network illustrated that in the integrated scheduling methods, LP1 (improving planning reliability), LP18 (increasing transparency), LP9 (identifying and eliminating of waste), LP11 (detecting and solving spatiotemporal conflicts), LP19 (enabling coordination of the look-ahead plans), and LP3 (continuous flow of work) have were given the most attention. These results indicate that in line with efforts to increase productivity in the construction industry, the focus of research and industry for project planning and scheduling is beyond cost, time and quality management, which has been of concern for years. Areas such as reliability, transparency, waste management, coordination in mid-term planning, and flow and process management are considered more attention in integrated scheduling systems. Moreover, attention to workspace management through location-based scheduling methods, such as LOB, LBMS, and LSM, as well as object-based scheduling methods, including 4D and BIM in integrated scheduling methods, lead to focus has been directed at LP11 (detecting and solving spatiotemporal conflicts).

In the other hand, LP14 (eliminating the root causes of variability), LP13 (scheduling of modular and off-site construction), LP17 (increasing safety on the construction site), LP16 (improving the usability of the 4D BIM for workflow analysis), and LP20 (implementing of pull flow control) have received the least consideration in integrated scheduling methods. The findings show that although learning and eliminating the root causes of variability is one of the important principles in lean construction and extensively studied in the early days of lean construction, it has received little attention in integrated scheduling methods, this issue can also be found in Aslam et al. (2020)'s research. One possible explanation is that lean construction is a subset of the broader idea of lean thinking, which embraces various principles and activities to enhance productivity and quality while minimizing waste. Variability may be managed holistically and completely by combining lean construction with other principles, including, collaboration and communication management, continuous improvement and visual management. By focusing on these proactive actions, the need to address variability as a separate issue may be reduced or managed indirectly. In addition, little emphasis has been given to the scheduling of modular and off-site construction in integrated scheduling methods, despite the fact that one way to incorporate lean production into construction project delivery would be to enhance off-site construction levels from materials, components and sub-assembly to modular buildings (Pasquire and Connolly 2002). Furthermore, 4D BIM capabilities have contributed significantly to the use of lean principles, such as LP6 (visualizing of schedules to understand and communicate content to a variety of stakeholders) and LP11 (detecting and solving spatiotemporal conflicts), and LP8 (schedule constructability analysis), in integrated scheduling methods. However, little attention is paid to the usability of the 4D BIM for workflow analysis. This gap can be investigated in future research on integrated scheduling methods.

Analyzing the co-occurrence of used lean principles in integrated scheduling methods, based on Figure3, depicts the pairs of LP1 (improving the reliability of the planning) and LP18 (increasing transparency), LP4 (decreasing workflow variability) and LP3 (continuous flow of work), and LP19 (enabling the coordination of the look-ahead plans) and LP11 (detecting and solving spatiotemporal conflicts) have been recognized as the most frequent pairs in integrated scheduling methods. According to these evaluations, considering lean principles in integrated scheduling methods focuses mainly on mid (look-ahead) and short-term (weekly work) planning.

In integrated scheduling methods such as BIM-LPS, and BIM-LPS-Kanban, which combine LPS and BIM capabilities, lean principles have been covered to a considerable extent; however, in order to apply these concepts practically, one must utilize more integrated methods to overcome the challenges of mismatched LoD in BIM and the granularity of look-ahead (Lin and Golparvar-Fard 2021) and weekly work plans, covering all scheduling levels, and taking contract and management requirements into account. For this purpose, the authors propose using location-based scheduling methods, such as LBMS and Takt Time Planning (TTP), for work structuring and solving the mismatching LoD in BIM with look-ahead and weekly work plans granularity by associating BIM components to their locations. Moreover, since CPM-based scheduling is a contractual obligation for many projects, including it in integrated scheduling methods will also address managerial and contractual concerns.

CONCLUSION

As a result of poor productivity resulting from ineffective project planning and scheduling in the construction industry, not only have numerous studies examined the integration of conventional scheduling methods with each other, lean tools and principles, but also, in practice, project managers and planners put a greater emphasis on using integrated scheduling methods for more effective project scheduling and control. To better understand the lean principles used in integrated scheduling methods, this study followed a multi-step methodology to analyze 26 identified integrated scheduling methods and 20 lean principles. To this end, a systematic literature review is conducted on the planning and scheduling field of study. After that, a quantitative analysis was performed based on SNA. The degree of centrality (DC) is determined to assess the importance of lean principles used in integrated scheduling methods. The result indicated that BIM-LPS-Kanban, BIM-LPS, LBMS-LPS-CPM, and BIM-LBMS, as some integrated scheduling methods, have utilized the most lean principles in their structures that indicate the most focus of academia and industry is on the LPS and BIM for developing the integrated scheduling methods.

As lean principles, LP1 (improving the reliability of the planning), LP18 (increasing transparency), LP9 (identification and elimination of waste), LP11 (detecting and solving spatiotemporal conflicts), LP19 (enabling the coordination of the look-ahead plans), and LP3 (continuous flow of work) have gained the most attention in the integrated scheduling methods. In addition, the pair of LP1 (improving the reliability of the planning) and LP18 (increasing transparency) were detected as the most pairs in integrated scheduling methods. The findings illustrate that the construction industry's push for improving productivity has led to a shift in research and industry focus away from traditional concerns of cost, time, and quality management in project planning and scheduling.

In contrast, LP14 (eliminating the root causes of variability), LP13 (scheduling of modular and off-site construction), LP17 (increasing safety on construction site), LP16 (improving the usability of the 4D BIM for workflow analysis), and LP20 (implementation of pull flow control) have paid the least attention in integrated scheduling methods. Despite the potential benefits of incorporating lean production principles into construction project delivery through increased levels of off-site construction, integrated scheduling methods have overlooked the scheduling of modular and off-site construction. This represents a gap in the current focus, as enhancing the use of off-site construction - from materials, components, and sub-assemblies to modular buildings - could be a viable strategy for achieving this goal.

Finally, this paper contributes to the body of knowledge by enhancing knowledge and awareness of the lean principles used in integrated scheduling methods in the construction industry.

The limitations of this research are the lack of analyzing correlation between lean principles and considering the expert's points of view for evaluating lean principles. Moreover, focusing on collaborative visual-based scheduling using new technologies such as Virtual Reality (VR)-LPS and metaverse-base LPS could be one of the suggestions for further research. Future studies should also focus on several lean principles, such as root cause analysis and corrective actions, the usability of 4D BIM for workflow analysis, and modular and offsite construction scheduling for integrated scheduling methods.

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